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ECE 520: VLSI Design
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Homework #2

1. An NMOS transistor has a threshold V_T of 0.5 V when its source–to–substrate voltage is zero, given that the substrate is uniformly doped at 2E17 acceptor dopant atm/cm^3 and the gate oxide capacitance is 3.5 fF/μm^2.

   (a) Determine an expression for the threshold voltage as a function of source–to–substrate voltage.

   Using the equation for body effect:

$$V_T = V_{T_0} + \gamma\left(\sqrt{|2\phi_F - V_{BS}|} - \sqrt{|2\phi_F|}\right) \tag{1}$$

$$\text{where } \gamma = \frac{\sqrt{2qN_A\epsilon_{Si}}}{C_{ox}} \tag{2}$$

   (b) It is desired to obtain a threshold voltage of 1.0 volt at 0 volts source potential (with respect to ground). One method suggested by engineering team is to provide a separate bias supply for the substrate, in order to increase the source-to-substrate voltage. What value of Vx supply is needed?

   Using equation (1) from part (a), plugging in values, we get:

$$V_T = V_{T_0} + \gamma\left(\sqrt{|2\phi_F - V_{BS}|} - \sqrt{|2\phi_F|}\right)$$

$$1\text{V} = 0.5\text{V} + 0.736\left(\sqrt{|0.87 - V_{BS}|} - \sqrt{|0.87|}\right)$$

$$V_{BS} = -1.73\text{V or } \cancel{3.47\text{V}}$$

$$\text{therefore } V_x = V_B = -1.73\text{V}$$

   (c) Rather than use a separate substrate bias generator, another group in engineering is suggesting to use a threshold adjustment implant in the fabrication. Assuming the implant acts as a sheet charge in the oxide-silicon interface (via the term Q_{fc}), what dose is needed to obtain $V_{TN} = 1$ volt at $V_{SB} = 0$? Would you use acceptor (N_A) or donor (N_D) atoms?

$$V_T = \frac{Q}{C_{ox}} - V_{T_0} \tag{3}$$

$$0.5\text{V} = \frac{Q'}{3.5\ \text{fF}/\mu\text{m}^2} - 0$$

$$Q' = 1.75\ \text{V fF}/\mu\text{m}^2$$

   This equates to 1.09×10^{12} cm^{-3} acceptor (N_A) atoms.